NASA EARTH SCIENCES

SENIOR REVIEW

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Submitted to:

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INTRODUCTION

A Senior Review Team met April 26 through April 29, 2005, to review proposals for extended missions for ACRIMSAT, ERBE, GPS Science[1], GRACE, ICESat, Jason, QuikSCAT, SAGE, Terra, TOMS, TRMM, and UARS. Two primary criteria were utilized in the review process: (1) scientific value and (2) relevancy of each proposal to NASA Earth Science Strategic objectives. The health of the instruments and spacecraft were also an important consideration. Education and public outreach (E/PO) are evaluated separately, and only noted briefly here.

The Senior Review Team found worthwhile and valuable science objectives in every single proposal for mission extension. We have provided both an absolute assessment of the proposed mission extensions in terms of the primary criteria and a ranked evaluation. Although ranking across the widely differing costs and scientific returns for the missions was difficult, an examination of all the proposals from many different angles yielded a consistent set of evaluations.

The Senior Review Team thanks NASA for their support throughout the process and the NRESS staff for creating an excellent working environment.

REVIEW PROCESS

Every proposal was examined by each of the Review Team members. Each proposer was provided the opportunity to present their proposal and to participate in a question and answer period with the entire Review Team. In addition, each proposal was assigned at least one primary reviewer and one secondary reviewer. These individuals were assigned two roles: to promote discussion on each proposal and to develop a draft of the review text for each proposal. The review draft for each proposal was then discussed by the entire Review Team prior to formulation of a final assessment.

In addition to an individual, absolute assessment of each proposal, the Review Team developed a relative ranking of the missions. Importantly, the Review Team examined both "in guide" and "optimal" objectives and budgets for each proposal, and then developed a single preferred course for action. It is these preferred courses of action detailed in each proposal assessment that were then ranked by the Review Team. The panel also noted the unique NASA role for specific types of measurements and the importance of the observations for non-NASA applications (e.g., operational weather forecasting), although this information was not utilized when determining rank.

Two different ranking methodologies were adopted. The first ranking method provides a relative ranking of the proposals. Each Review Team member was constrained to assign a unique number to each proposal (1 to 12), where "1" was assigned to the strongest

[1] "GPS Science" is the short name used in this report for the activities proposed as the "GPS Atmospheric Limb Sounding Mission".

proposal and "12" to the weakest. An average rank and standard deviation were calculated from the full set of Review Team scores. High standard deviations prompted additional discussion after which the ranking method was repeated and finalized (figure 1). A relative ranking from 1 to 12 orders the proposals from strongest to weakest, but does not reveal whether the ordering separates nearly equal proposals all of which are of compelling scientific value or whether the ordering separates a set of compelling proposals from other more modest proposals. Consequently, a second ranking method was formulated that considered scores based on an assessment of future scientific value and relevancy to NASA Earth Science Strategic objectives (10-8 compelling; 7-4 excellent, but less compelling, and 3-0 modest). Each Review Team member was allowed to assign the appropriate level of scientific value to each proposal. Figure 2 provides a ranking based on anticipated future scientific value.

The Team notes that the ranking of scientific value and comparison to cost is for the proposed science within the mission proposal and does not include an assessment of the scientific efforts of other researchers who access and utilize these measurements.

RANKINGS

Figure 1. Relative rank of each mission with 1 being the highest rank and 12 the lowest.

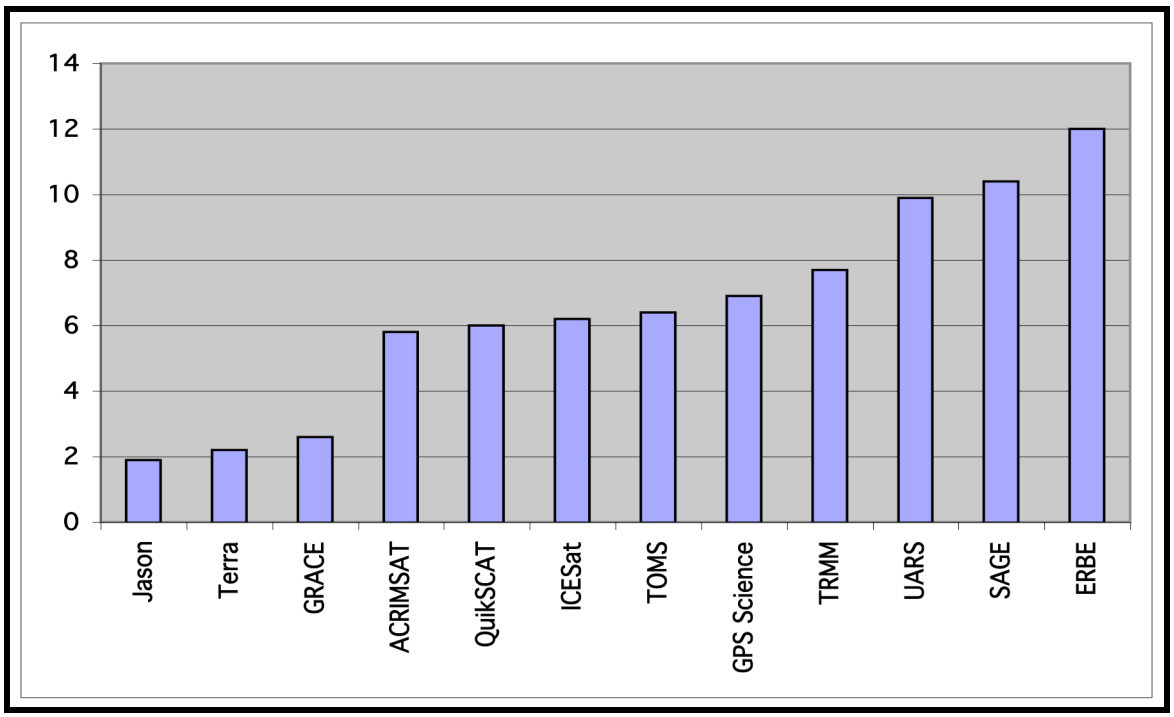

Table 1. Statistics for Senior Review Team relative rankings.

Mission	Min	Max	Average	Std Dev
Jason	1	5	1.90	1.29
Terra	1	4	2.20	1.23
GRACE	1	5	2.60	1.07
ACRIMSAT	4	9	5.80	1.62
QuikSCAT	2	9	6.00	2.36
ICESat	3	8	6.20	1.93
TOMS	3	9	6.40	2.12
GPS Science	4	10	6.90	1.91
TRMM	5	11	7.70	2.16
UARS	6	11	9.90	1.52
SAGE	9	11	10.40	0.70
ERBE	12	12	12.00	0.00

Figure 2. Rank based on absolute scientific value (10-8 compelling; 7-4 excellent, but less compelling, and 3-0 modest).

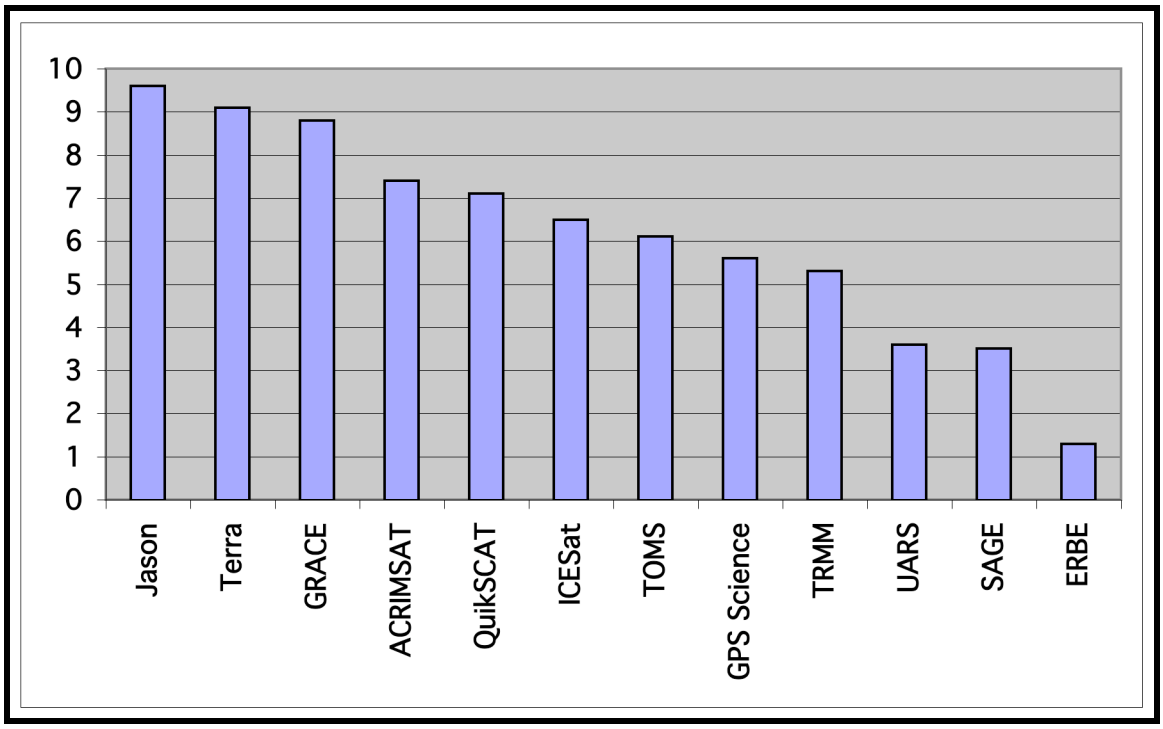

Table 2. Statistics for Senior Review Team rankings of future scientific value.

Mission	Min	Max	Average	Std Dev
Jason	7	10	9.60	0.97
Terra	7	10	9.10	0.99
GRACE	7	10	8.80	1.03
ACRIMSAT	6	9	7.40	0.97
QuikSCAT	4	9	7.10	1.45
ICESat	4	8	6.50	1.18
TOMS	5	8	6.10	0.99
GPS Science	3	8	5.60	1.65
TRMM	4	7	5.30	1.34
UARS	2	7	3.60	1.43
SAGE	2	5	3.50	0.97
ERBE	0	3	1.30	0.82

COMMON ISSUES

In the conduct of the review, the Senior Review Team noted several common issues:

1) There is tremendous value in the integration of measurements within platforms and across missions. In fact, this integration has long been viewed as a real strength of the NASA Earth Sciences strategic enterprise, and was even a major "selling point" of flagship missions such as Terra and Aqua. In general, much of this integration has not yet been realized. Most of the proposals focused on the contributions from their specific instrument. In part this reflects the complexity of the enterprise and the demands on individual teams to achieve specific goals for providing data and data products from specific instruments. We believe that NASA and the scientific community would benefit from a more deliberate effort to promote integration and synergism, including the development of interdisciplinary science teams designed to develop innovative results using multiple instruments and platforms.
2) The Team noted that the mode in which NASA develops scientific teams was highly variable. This variability includes cases where (a) data and algorithm providers were also in a position to select the related science team, (b) science teams directly incorporated in extension proposals, and (c) science teams competed through the R&A program. In addition, funds to support future missions were sometimes embedded into a heritage instrument, and in other cases funds were identified specifically with a planned mission. In general, the Review Team believes a more consistent approach could be adopted. In our view, the best process is one in which science teams are selected through a competitive process and in which the funds for future missions are identified with science teams specifically developed for those future missions.
3) The education and outreach components of each of the proposals often reflected a sub-critical set of activities. Further, contact with schools tended to be tied to the location of the PI or supporting scientists. Web pages were associated with specific instruments or maintained by centers. This seems problematic. The Review Team is not suggesting that each investigator invest more time in educational activities. Rather, the Earth Sciences education and outreach effort might benefit from a more coordinated, central approach to web pages and the development of materials for dissemination, as well as efforts to connect with a broader community of teachers, as well as the general public. The Review Team also recognizes that these efforts have been recently reviewed by a separate panel and are only an ancillary part of the Senior Review process.

Project Name: ACRIMSAT

Active Cavity Radiometer Irradiance Monitor (ACRIM) measurements are providing a record of Total Solar Irradiance (TSI) as part of the EOS program. ACRIMSAT was launched in 1999 on a small, dedicated satellite and carries the ACRIM3 instrument. The SORCE/TIM instrument was then selected as a second instrument as a part of the EOS program. The key proposal is to provide overlapping measurements required to maintain a long-term record of TSI until the NPOESS operational time period. The current operation of both TSI instruments provides a level of redundancy that would prove key if either fails.

Spacecraft /Instrument health and status: Spacecraft and instrument health and status are excellent. The spacecraft is 100% operational with the potential for an additional 10 years of life. There are no expendables and the spacecraft maintains redundant systems. The instrument is also 100% operational. The three Active Cavity Radiometers have excellent performance margins. There is degradation in the primary monitoring sensors of 3 ppm per year, but this can be corrected by the other two radiometers.

Science Strengths: A continuous record of TSI is extremely important. Any gap presents a significant problem in reconstructing the record (any trend analysis becomes nearly impossible). Overlap between instruments is therefore essential and some level of redundancy ensures overlap. ACRIM3 and SORCE/TIM have the potential to add sufficient TSI measurements to gain a record for three successive solar minima. This will enable NASA to assess a major debate with regard to suggestions that there is a 0.04% per decade trend in TSI. ACRIMSAT health suggests that it has the potential to extend Total Solar Irradiance record without gaps and to ensure redundancy. It is not clear that NPOESS will step up to the responsibility of a continuous climate quality data record with overlap.

The science team for ACRIMSAT is very capable and also has the expertise to extend the useful record into the past through re-examination of the Nimbus7/ERB/ERBS/ERBE data (improving upon the so-called PMOD composite).

Relevancy Strengths to Earth Science Strategic Plan: ACRIMSAT directly addresses the Earth Science Strategic Plan objective "to understand and quantify the effects of "forcings" on the climate system produced by the Sun's solar variability." The measurement is fundamental to assess future climate change, to improve future predictions, and to better attribute the causes of climate change. No additional TSI missions are planned before NPOESS (2012), heightening the importance of both ACRIM3 and SORCE/TIM, making sure that one of these instruments will maintain the continuity of the TSI record.

As an added note, ACRIMSAT also makes an excellent contribution to emerging Earth-Sun connections efforts enabling both Space and Earth sciences.

Data operations (accessibility, quality control, archiving): ACRIM experiments provide Level 0 and Level 2 fully calibrated and validated daily mean and shutter cycle results, with a 90-day validation period. The data are formulated for ESDIS and distributed through the LaRC DAAC. ACRIM provides a website for data products, ancillary results, composite TSI, general research results. These results are widely used by solar and climate communities.

E/PO comments: There is a reasonable set of educational and outreach efforts including:

Independent web site (JPL)
Informational materials
Public events and science conferences
Graduate students
Middle school efforts

Proposal Weaknesses: Intercomparison of ACRIM3 with SORCE/TIM is mentioned as a priority but not listed as a major objective (based on the list of bullets described as objectives). Such cross-calibration should be a requirement.

Baseline and optimum missions: The two budget scenarios are identical. The proposed budget is to extend operations for four years (FY06-FY09) with a minimal but adequate team. The budget allows for daily contact with spacecraft, data handling from processing to archiving, and will support the scientific analysis and publications.

Overall assessment: ACRIM3 continuation will achieve continuity of the TSI measurements which are essential to the Earth Sciences and which require redundancy and overlap between missions. However, SORCE/TIM appears to be an additional source of redundancy. We would expect that the next Senior Review would be tasked with determining the best mechanism to ensure redundancy and overlap in TSI measurements.

Our concern is whether ACRIM3 is the only and the best solution for achieving continuity of the TSI measurements. The request to continue ACRIMSAT is partly predicated on the view that SORCE/TIM may not be continued beyond its nominal mission time. SORCE/TIM was not evaluated as part of this Senior Review Process. ACRIM3 is also being used as the standard for piecing together earlier TSI measurements from different missions.

Project Name: ERBE

The proposed mission relates to continued operation of the Earth Radiation Budget Experiment (ERBE) non-scanning radiometers, data collection and processing for FY2006-09. The ERBE proposal was for the science operations of that instrument on the ERBS spacecraft. The SAGE proposal included the resources to operate the ERBS spacecraft. A primary objective of ERBE is to collect a long-term climate data set of TOA shortwave flux (0.3 - 3.5 μm), longwave flux (3.5 - 100 μm), and net flux. This data set now includes 20 years of measurements. The ERBE data also provide an independent measurement of the Earth's radiation for comparison to Cloud & Earth Radiant Energy System (CERES) on Terra and Aqua. The ERBE non-scanning radiometer package includes a solar monitor, which has provided two decades of Total Solar Irradiance (TSI) measurements. Unfortunately, these measurements are not considered by the TSI community to be state of the art when compared to other measurements from ACRIMSAT.

Spacecraft /Instrument health and status: Although providing very relevant and high quality data for many years, the spacecraft has experienced problems since October 1999, when the instrument drive assembly failed at an angular position of 15 degrees away from Earth nadir. This failure caused a portion of the secondary aperture and the instrument housing to partially obstruct the full view of the Earth disc. In addition, the elevation assembly failure prevented on-board calibrations, resulting in the Earth irradiances not being calibrated with the on-board system. In was not until December 2002 and September 2003 that the spacecraft was rotated to observe the Sun that this calibration issue was corrected. The validity, as well as the approach, of extending the December 2002 calibration three years back to the October 1999 failure was not discussed nor were preliminary results presented. The proposed extended mission is to support this calibration effort. This is a critical flaw and their ability to generate climate quality data is doubtful.

Science Strengths: It has acquired over 15 years of radiation budget data and 20 years of TSI. This is the longest continuous record to date. Besides CERES it is the only global radiation budget data for climate change.

Relevancy Strengths to Earth Science Strategic Plan: Besides CERES it is the only global radiation budget data for climate change.

Data operations (accessibility, quality control, archiving): Relatively little cost to process data.

E/PO comments: The Review Team does not have additional comments beyond the assessment and recommendations of the prior E/PO review.

Proposal Weaknesses: There are issues concerning calibration of the instrument after Oct 1999. There was no discussion of how they plan to extrapolate 3 years back. How

does this new and innovative approach for calibration provide similar quality and measurement uncertainties as the previous on-board calibration system? The PIs indicate that the instrument maintains a high degree of precision and remains well calibrated, but no results were presented. All of the Earth radiation budget figures in the proposal do not have data after the 1999 failure. Some effort should have been made to present these data with estimates of the potential climate quality value once the new calibration has been applied. This was a critical flaw in the proposal. Comparisons between CERES and ERBS should have been made, but because of the uncertainty of the data after 1999 this was not possible. The ability to generate climate quality data records is in question. The spacecraft operations, including data collection, are assumed to be covered under the SAGE proposal. This is viewed as a weakness, since this proposal is partially dependent on the success of the SAGE proposal.

Baseline and optimum missions: The PIs are not requesting funds for scientific investigations, just the support for calibrating the data and extending the mission. The costs for the data and science that would be derived from the extension of the mission seem to be a great buy. The optimal budget was to support Science Data Analysis that would include semi-annual azimuthal operations for instrument calibration. The in-guideline budget has very little scientific merit, as the data will not be calibrated. There still is the question that the optimal budget would support the generation of climate quality data.

Overall assessment: The ability of ERBE to generate climate quality data is doubtful and the TSI contributions of ERBE are not state-of-the art and therefore continuation of ERBE is at the lowest priority of the missions reviewed by the panel.

Project Name: GPS Atmospheric Limb Sounding Mission[2]

Measurement of the refractive index and path delay of the radio signals emitted from the Global Positioning System (GPS) constellation of satellites when received by receivers on satellites in low Earth orbit can give valuable information on temperature, moisture, and electron density profiles. These measurements are accurate and have excellent altitude resolution and are inexpensive to obtain since they utilize the large investments made to implement the GPS constellation for other purposes. This proposal seeks to produce these profiles and support scientific research using these measurements.

It is proposed to use data from receivers on a variety of missions – CHAMP, SAC-C, GRACE, and COSMIC. There is no doubt that profiles derived from these missions will give very valuable data that can be used for many purposes that include weather forecasting, space weather, and are of climate quality. The number of satellites that utilize the receivers that have been developed by this group at JPL will likely grow substantially in the future, so these types of measurements will likely become even more important in the future.

Spacecraft /Instrument health and status: This proposal does not relate to a single mission, or missions, as do the others. Rather, it seeks to maintain an algorithm team (baseline) and a science team (optimal) for analysis of GPS signals from several spacecraft.

Science Strengths: GPS profiles have high vertical resolution, can be obtained in all weather conditions, and can yield temperature, moisture in the lower atmosphere, and electron density in the ionosphere. With a number of satellite receivers, good geographical coverage is obtained. These data are useful for NASA's weather, climate, and space weather objectives.

Relevancy Strengths to Earth Science Strategic Plan: This project is very relevant for NASA's weather, climate, climate processes, and space weather objectives. The proposing group is very expert in deriving the GPS profiles but has much less expertise in the scientific areas that they propose to explore.

Data operations (accessibility, quality control, archiving): The mission group seems to have capable data operations with good accessibility, quality control, and archiving, and they have a good, but modest, E/PO activity.

E/PO comments: The education and outreach efforts are very modest.

Proposal Weaknesses: While there are some excellent people on the proposed science team, the proposal makes a number of claims which seem to be overly optimistic in many

[2] This report uses the shortened name "GPS Science" for this project.

aspects and just wrong in some others. For example, their statements on tropopause and gravity wave research are a bit naïve.

Baseline and optimum missions: The baseline proposal is to maintain the algorithm team to obtain profiles. The optimal mission seeks to maintain an associated science team.

Overall assessment: The Senior Review Team believes that support of an algorithm team to work on GPS data would be valuable and would yield profiles of excellent quality that would serve many purposes. However, there are two primary concerns that should limit support of this initiative: (1) insufficient knowledge among the PIs to tackle all of the science issues in depth, and (2) failure to address funding support related to the different missions that will provide data.

The proposal does not address the issue that COSMIC is only currently funded for two years of operation (2006 and 2007). It is also not clear whether the COSMIC program will generate similar products, irrespective of NASA's support. Their justification was that the enhancement via QC/QA efforts on the data acquisition and processing would insure that the data would be of climate quality. The support for this effort should probably come from a science NRA.

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Project Name: GRACE

The Gravity Recovery and Climate Experiment (GRACE) mission is a first-of-its kind mission. It has provided a much more accurate Earth gravity model and detected regional changes in gravity that reflect mass movements in the Earth system for the first time. This has been a partnership with Germany. GRACE is the first successful mission in NASA's Earth System Science Pathfinder mission series and has completed three years of operation. While it was proposed as a 5-year mission now in its 4th year, it has been allocated resources commensurate with the 5-year effort. NASA HQ asked the Panel to review the science program for 2006 and 2007 as well as comment on the project's request for an extended mission phase commencing in mid-2007.

Spacecraft /Instrument health and status: The mission continues to operate successfully with very little degradation. The expected life of the system exceeds 10 years. To mitigate atomic oxygen damage, there is a plan to switch the leading and trailing satellites halfway through the mission. This maneuver has been delayed pending decision on extension.

Science Strengths: The GRACE mission has delivered a series of mean gravity fields of improving and unprecedented quality. The latest GRACE model, GGM02C has a less than 1 cm geoid-height error at a resolution of 300 km. This is comparable to the accuracy and resolution of the Jason-1 and TOPEX/Poseidon radar altimeter topography measurements. The combination of these measurements provides a credible estimate of absolute ocean dynamic topography at 300 km resolution the first time. This satisfies the GRACE NASA Level 1 requirement for Minimum Science Mission.

The extended mission would focus on the time-varying gravity field. The GRACE mission has distributed the first-ever 24 monthly gravity fields (plus all input data) permitting studies of the time varying gravity field at much higher resolution and accuracy than previously possible. In addition, overall accuracy of the GRACE determined gravity fields has increased by an order-of-magnitude over the past three years and will continue this incremental improvement as a variety of input models improve, especially air pressure. A new reprocessing will be carried out this year. The initial results have detected hydrologic, ice sheet and ocean movements. These early results are expected to expand with the addition of a science team that was selected through and funded by a competitive NRA process in early 2004.

Relevancy Strengths to Earth Science Strategic Plan: The GRACE mission provides a unique integrated measure of the Earth System. Consequently, it addresses some important aspects of the Earth Science strategy, including monitoring global ocean circulation and its role in Earth's weather and climate; tracking mass variations in large ice-sheets; and measuring Earth's gravity field and its variations over time, with unprecedented accuracy, to assess shifts in the global water cycle.

Data operations (accessibility, quality control, archiving): Over 360 international users are downloading GRACE Level 1 and 2 science products. The produced fields will be distributed after 60 days of receipt. GRACE science data products are delivered to the public through the JPL PO/DAAC and by a mirror site in Germany at GFZ Potsdam.

E/PO comments: The Review Team does not have additional comments beyond the assessment and recommendations of the prior E/PO review.

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Proposal Weaknesses: Despite the completion of the third year of the mission and wide dissemination of the data, the publication list is small. The proposal could have done a better job of emphasizing the benefit of coordinating these observations with other NASA supported missions, such as Jason-1 and ICESat. The potential use of the aft GRACE GPS receiver on a non-interference basis for atmospheric profiles of temperature and water vapor, as well as air pressure, was not addressed. We believe that it should be addressed judiciously.

Baseline and optimum missions: The baseline mission proposes to extend the mission from 5 to 8 years. The optimum mission would address risk reduction in the flight system and improve operating efficiency through some FY06 augmentation.

Overall assessment: The Review Team is highly supportive of an extension of GRACE at the optimal level (continuation of the mission, addition of a separately competed science team, integration with other observations, and improvement of the error budget), because of its value as an integrator of Earth System Science information and the significant benefit of contemporaneous flight of Jason-1 and ICESat. Wider dissemination of the results, through publications, should be an added emphasis for the extended phase. NASA should address improved validation efforts even if it requires additional funding.

The benefit of contemporaneous flight of Jason-1 and ICESat, as well as improved land, ocean and atmospheric models will continue to improve the accuracy and science of GRACE. Experiments to enhance spatial resolution, such as reducing spacecraft separation or reducing altitude are encouraged by the panel, as appropriate. The panel noted the complexity of the observation and the difficulty in addressing validation. However, the committee believes that improved validation efforts may be needed even if it requires additional support for ground based observations (e.g., pressure gauges in the deep ocean). Finally, evaluations of the potential applications of GRACE observations beyond Earth sciences are warranted.

Project Name: ICESat

Launched in January 2003, NASA's Ice, Cloud and Land Elevation Satellite (ICESat) is providing first-of-its kind laser-altimeter measurements from ice sheets, clouds, oceans, and terrestrial surfaces. While the mission has legacy from previous laser altimeter missions on the Space Shuttle and the Mars Orbiter Laser Altimeter (MOLA), it represents the first Earth-observing mission on a permanent satellite platform. The primary science goal of ICESat is to quantify ice sheet mass balance, but the mission also addresses other science objectives including cloud structure and climatology, vegetation cover, hydrology, and land surface elevations.

Spacecraft /Instrument health and status: There are several instrument failures with ICESat that have already reduced data collection and quality. To avoid cost overrun, the Science Team accepted before launch a beam-FOV bore-sight misalignment that has significantly impacted pointing uncertainty. Failure of Laser 1 after just 36 days and severe power decline in Laser 2 has made the remaining lifetime of Laser 3 (and Laser 2, in its limited remaining capacity) of paramount concern. Extrapolation of Laser 3's current decline rate indicates that approximately 180-250 days of lifetime may remain, but this remains highly uncertain and its true lifetime remains largely unknown.

Further, loss of the 532 nm data has resulted in loss of atmospheric science data and introduced additional complications, particularly with regard to atmospheric retrievals and "cloud-clearing" for the 1064 nm data. The ICESat team is working on algorithm development to enable better cloud-clearing and optical thickness estimates from the 1064 nm data alone, but it is clearly a complex problem that will require significant effort to mitigate.

Science Strengths: The precision of ICESat elevation retrievals over ice sheets is superior to other existing spaceborne (e.g., radar) altimeter systems, enabling much better estimates of ice sheet topography. In Antarctica, recent discovery of glacier flow acceleration and tremendous thinning in response to the disintegration of "buttressing" ice shelves is a remarkable and sobering scientific observation, with serious implications for the possibility rapid sea level rise. ICESat retrievals of sea-ice freeboard have enabled for the first time areal estimates of sea ice thickness (not just extent and concentration). Preliminary findings show ice thinning that may represent either interannual variability or secular change, but the fact that sea ice thickness can be measured at all is a demonstration of major importance. These are extremely exciting new observations that could not be made in the absence of ICESat.

ICESat preliminary data have revived interest in ancillary science, e.g., estimation of forest canopy height and possibly biomass/structure, and robust estimates of free water surface elevations and slope on rivers and lakes. Other features for which useful ICESat retrievals have been demonstrated include cloud heights and structure, land topography, and surface elevations of small glaciers and ice caps. Clearly, further ICESat data of these targets would provide a benchmark for algorithms and satellite design of future spaceborne lasers.

Relevancy Strengths to Earth Science Strategic Plan: The primary mission objective of ICESat is to achieve mass balance estimates for the major ice sheets on Antarctica and Greenland. As such, it directly impacts NASA's "Climate Variability and Change" focus area. In addition, it supports this same focus area through limited sampling of global cloud characteristics and ocean topography. NASA's "Water and Energy Cycle," "Earth Surface and Interior" and "Carbon Cycle and Ecosystems" Focus Areas are impacted most significantly by ICESat observations of river level, Earth topography and/or deformation, and forest cover, respectively.

Data operations (accessibility, quality control, archiving): A somewhat different aspect of ICESat's data operations is its reliance on investigator-led processing systems (I-SIPS) for generation of standard data products. The I-SIPS staff supports operations, system administration, testing of the Geoscience Laser Altimetry (GLAS) Science Algorithm Software, and scheduling. At the time of writing, the Laser 1 data have been reprocessed and released 7 times. Data from Lasers 2 and 3 are in various stages of processing or reprocessing as new corrections and algorithm adjustments are made.

E/PO comments: Beyond provision of useful materials, educational outreach has not been a focus of the ICESat effort. ICESat has maintained a high level of visibility in the public media as well as in scientific circles. Several press conference and special sessions have been carried out at meetings of the American Geophysical Union. In addition to data products, a number of visualizations, graphics, brochures, etc. have been disseminated.

Proposal Weaknesses: A major weakness in ICESat is its inability, as stated in the extension proposal, to meet the major mission objective of determining the mass balance of the major ice sheets. The proposal did not describe fully the serious diode failures/degradation of the ICESat lasers. This problem goes to the heart of risk assessment for ICESat's future and deserves serious consideration in the document. However, engineering data showing performance/degradation of all three lasers was presented in person to the panel, and was discussed at length both during and after the presentation.

Baseline and optimum missions: The provided budget is not fully transparent, and needs to be broken down more explicitly. The panel was confused by the fact that the submitted optimal budget is below the submitted guideline budget, while the submitted "guideline" budget lies above the actual NASA guideline. This is likely to have arisen from the fact that the ROSES allocation is subtracted from the optimal scenario. However, because of the lack of clarity the panel does not feel sufficiently informed to make an assessment regarding the optimal versus bare-bones scenarios.

Overall assessment: The overall sense of the Review Team was that the measurements and data being generated by ICESat should be continued as they are unprecedented, scientifically exciting, and place NASA at the forefront of a cutting-edge new technology in space-based remote sensing. However, the Team believes that an expert panel should

be convened to determine the best use of the remaining laser lifetime as it does not appear that the primary science objective of ICESat can be achieved.

It is also clear that ICESat is providing information and data on the performance of space-based laser systems that will be invaluable for the design of future missions. Panel unease stems primarily from the failure of a significant portion of the sensor system and the highly uncertain future of Laser 3, and whether the Science Team's adjusted mission plan for ICESat is optimal for gaining the absolutely maximum science benefit from its remaining lifetime.

A notable concern of the panel was whether or not the primary science objective (i.e. ice sheet mass balance) can still be achieved in ICESat's remaining lifetime. It is important that this issue be either affirmed or refuted by an independent expert panel, because the answer to that question strongly determines whether the new intermittent 33-day sampling cycle proposed to extend laser lifetime is optimal. Put another way, if it is unlikely that the primary science objective will be met, then the question arises whether the remaining laser life should be used in another way (e.g., a focus on seasonal variability or even non-ice applications). Also, "turning-off-and-on" the laser adds complexity to the mission so the scientific arguments for doing so should be more clearly articulated. Indeed, since a long-term climate record is highly unlikely, running the laser continuously might provide a more optimal data set and reduce the cost of an extended mission.

If review of the operations plan indicates that the primary science objective is in fact unlikely to be attained, then the panel believes that a formal re-evaluation of ICESat's mission schedule and science objectives by conducted an expert panel, would be important in order to identify the maximum scientific value that may still be obtained from the mission.

The panel endorses greater use of the scientific utility of ICESat observations (including all non-ice applications) through competitive selection of research proposals, and is pleased to note such activity through ROSES 2005.

Project Name: Jason-1

Jason-1 is a joint NASA and the French CNES mission to provide high quality sea surface topography measurements for ocean circulation and sea level change studies. The mission is a follow-on to the highly successful TOPEX/Poseidon mission (T/P). Both Jason-1 and T/P are operating successfully and have provided revolutionary impacts on ocean and climate science. The proposed mission is to extend the sea surface topography climate record for 4 years to build a 16-year record and provide continuity with the future OSTP or Jason-2 mission to be launched in 2008. This would address recommendations of the U.S. Climate Change Science Program strategic plan. The optimum mission would continue to operate T/P (for a limited time of about 1 year) as well as address unique exploratory ocean science on mesoscale processes, upper ocean circulation, and continental shelf processes from a tandem mission. These measurements are utilized by operational agencies.

Spacecraft /Instrument health and status: Jason-1 and T/P are functioning successfully but there have been some equipment failure and loss of redundancy. There is an 11 cm bias between the Jason-1/Poseidon-2 and TOPEX/Poseidon altimeters that needs to be resolved.

Science Strengths: The Jason-1 altimeter measurements of ocean topography overlap those from T/P and form an uninterrupted global description of sea height changes and ocean circulation for the past 12.5 years at cm accuracy and 300 km resolution. Ocean topography provides unique integrated information of ocean heat, freshwater content and momentum, in addition to providing a global view of sea level rise. These data have been examined by a large international team of scientists funded by NASA NRA processes and CNES. Their landmark accomplishments have been documented in over 1,974 publications. This effort provides tremendous science benefits and integrates measurements from other NASA missions, as well as a growing network of global in situ observations such as the new profiling float network for upper ocean temperature and salinity, ARGO. For example, these observations provide an assessment of heat and mass contributions to sea level rise and estimates of ocean heat storage in the overall energy balance of the planet. Satellite altimetry is a key component of the strategy for an integrated ocean observing system.

Relevancy Strengths to Earth Science Strategic Plan: Extending observations of sea surface topography to decadal scales is essential to the implementation of NASA's 10-year goals in addressing the fundamental questions: *"How is the Earth changing and what are the consequences for life on Earth"* and *"How can predictions of climate variability and change be improved."* The observations will address two long-term agency goals (10 year Outcome): - Reduce uncertainty in global sea level rise projections by 50% by the year 2014. - Enable 10-year or longer climate forecasts by the year 2014.

Data operations (accessibility, quality control, archiving): Since the commencement of the 10-day science repeat cycle on January 15, 2002 Jason-1 has delivered 98% of its data, which exceeds the mission requirement of 95%. Science data processing is

performed jointly by JPL and CNES. Data distribution and archiving functions are performed jointly by NASA PO/DAAC and CNES AVISO. Data products are distributed to over 2,800 users in over 50 countries.

E/PO comments: The Review Team does not have additional comments beyond the assessment and recommendations of the prior E/PO review.

Proposal Weaknesses: The proposal did not articulate the benefits of the optimal budget scenario that would support the tandem mission. In addition, they should have addressed plans for comparing and correcting the 11 cm bias between Jason-1/Poseidon-2 and TOPEX/Poseidon.

Baseline and Optimal Missions: The baseline mission can provide an unprecedented 16-year record of sea surface topography at a useful accuracy and resolution for ocean circulation and sea level rise science. The optimum mission will provide unique science, including order of magnitude improvement in the accuracy of coastal tidal models, and high-resolution ocean near-surface currents. Continuity with future missions is critical and will be addressed by the minimum mission scenario. Plans are to continue this record with Jason-2 (OSTP) and Jason-3 into the NPOESS era.

Overall assessment: The Review Team is highly supportive of continuing Jason-1 at the optimum level because of the opportunity to extend high quality sea surface topography measurements for ocean circulation and sea level studies to a 16-year record and to provide continuity with future missions. A tandem mission would be a one-of-a-kind science opportunity.

Project Name: QuikSCAT

NASA's Quick Scatterometer (QuikSCAT) was launched in June 1999 with a primary science mission of obtaining global measurements of near-surface ocean winds. QuikSCAT has subsequently emerged as the premier and only currently operating space-based instrument providing frequent global estimates of wind speed and direction over oceans. Its relative importance has increased in light of JAXA scatterometer mission failures and the fact that ESA's forthcoming ASCAT will have spatial and temporal resolutions inferior to QuikSCAT. In addition to its varied scientific contributions (with non-ocean applications being notably under-developed at present), the quality, consistency, and rapid data processing of QuikSCAT's wind field data have led to heavy usage by other agencies for weather forecasting and data assimilation models.

Spacecraft /Instrument health and status: QuikSCAT was launched in mid-1999 and is operating well on prime elements with redundancy still available. There is every anticipation of continued operation for at least 2+ more years.

Science Strengths: QuikSCAT provides the only ocean wind vector (speed and direction) measurement capability using a high confidence (i.e. familiar to science and operations communities) scatterometer approach. QuikSCAT has provided the measurement accuracy required by the physical and air-sea flux communities. This is the only current mission and means to routinely provide global, high-quality wind vector data. These fields provide the best source of wind forcing for ocean circulation studies, including ocean or coupled climate models, and are just starting to be used for studies of seasonal-to-interannual variability.

QuikSCAT also has superior swath width and resolution to the forthcoming ASCAT mission. QuikSCAT has the capability to make higher spatial resolution (5x25 km) wind vector measurements if enhanced resolution mode is implemented in extended mission. This opens the possibility of coastal science and meteorology.

QuikSCAT can make measurements of sea ice coverage and ice edge through clouds but other, operational satellites also do this using passive radiometry (SSMI, SSMIS etc). Better cloud penetration may be an advantage for scatterometry.

QuikSCAT has some capability to make soil moisture measurements over large areas. It is unclear whether this capability is superior to passive microwave (see above). Better cloud penetration may be an advantage for scatterometry.

The possibility for improved spatial resolution (proposed under the optimal plan) could be particularly beneficial for scientific study of coastal processes. However the panel was uncertain about whether the quality of existing coastal models will be sufficient for optimal wind retrievals in these areas.

Relevancy Strengths to Earth Science Strategic Plan: QuikSCAT contributes directly to 3 of 6 "key science focus areas" identified in the 2003 Earth Science Research Strategy, namely (1) Climate Variability; (2) Energy and Water Cycle; and (3) Improving Weather Forecasting.

QuikSCAT can contribute to improved predictions of *climate variability* via compilation of an ocean wind climatology that includes a variety of climate relevant conditions. The major contributions to this area from the *extended* mission are:

- Refined measurements in extreme conditions – the extended mission will encounter more extreme events than the current data set. This will include more high intensity tropical cyclones and more examples associated with intensification of storms.
- Measure long term changes or trends in ocean wind vectors associated with decadal scale phenomena – the extended mission will make measurements during phases of coupled ocean atmosphere systems, including ENSO/PDO/NAO, that have not been encountered since 1999.
- A 10-year time series of global winds would meet one of the original objectives of NASA EOS and the U.S. Global Change Program.
- The proposed increased resolution mode will open up measurements relevant to coastal meteorology and circulations– wind forcing is a key element of coastal ocean models and the increased resolution mode will add important observational data to their testing and validation. Coastal effects on ocean circulation and ocean circulation models are beginning to be considered and studied.

QuikSCAT can contribute to *water cycle* dynamics via ice cover measurements and possibly contribute to soil moisture. The uniqueness of the contribution can be tested in the extended mission.

Ocean wind vector data, when assimilated, makes a very important contribution to current Numerical Weather Prediction skill.

QuikSCAT has demonstrated a unique capability to act as a *transfer standard* for buoy data, which is sparsely sampled, to future ocean wind vector measurements (via overlap with ASCAT) such as CMIS. The importance of this capability is independent of measurement type and could make a vital contribution to the future use of operational sensors to climate measurements.

Data operations (accessibility, quality control, archiving): QuikSCAT is a reliable source for operationally relevant ocean wind vector data. Despite being a research satellite, the data are accessible, usable and timely enough to be used operationally. Data operations have been successful in meeting the rapid turnaround and consistency requirements for this use.

Work is ongoing on a "rain flag" for optimal wind speed retrievals during severe events.

E/PO comments: E/PO activities are broad, including educator workshops, schools programs, and museum displays in addition to the normal web sites and data products.

Proposal Weaknesses: The importance of extended mission to science goals is not as well established in the proposal as its operational relevance. A stronger case should have been made for the need for a 10-year record (vs the current 6-year record) of accurate surface vector winds for climate scale ocean circulation studies. Wind direction is the added measurement and certainly has unique contribution to make. The primary value of the extended mission is probably information regarding correlations and relationships of wind direction with the mesoscale components of interannual and decadal circulation events or phenomena. These are important questions but dependent upon missions (e.g., high resolution altimetry) that capture these phenomena. This science case would be much more compelling if this capability were available or planned.

The enhanced program adds higher resolution wind measurements. The contributions of enhanced resolution to coastal meteorology and science are very tempting but the clear science contributions in this area were not identified. We believe that an enhanced science team with expertise in this area will be important to exploit a potentially enhanced capability.

Non-ocean applications (e.g., snow/ice melt, soil moisture, vegetation cover) are not well developed in the proposal – this may sell it short somewhat as there is exciting science also developing in these other areas. The panel found itself pressing the new science more than the QuikSCAT team. There may be many reasons for this including that QuikSCAT's operational relevance is so strong that it may overwhelm the importance of scientific investigations in the team.

Baseline vs. optimal budget: As just described, it was not clear to the panel that the science impacts on coastal applications were sufficiently demonstrated to justify the full optimal budget. The panel also felt that the potential for stronger science impacts may well lie in non-ocean applications (e.g., freeze/thaw, ice sheet melting, soil moisture, and vegetation change), but these objectives received little attention in the proposal. Therefore, the panel gave strong priority to continued production of QuikSCAT global wind retrievals, but did not feel the "new" science, as currently articulated in the proposal, justifies optimal funding.

Overall assessment: The value to operational meteorological forecasting and as a transfer standard are very compelling arguments for the continuing mission. The utility for these observations for climate, through their ability to provide a substantially improved 10-year estimate of wind forcing of the ocean, will be a major outcome of the extended mission. The Review Team believes that the mission would benefit from involvement by a broader community of scientists and that there is room for re-assessment of the proposed budget.

The optimal proposal primarily added high resolution winds but, as noted, the impacts on coastal science were not clearly articulated. The panel believes that a 'scrubbed down' budget is needed. This version should either clearly state how the added measurements will translate to added science value or only identify the costs of the different data type. It

should be possible to evaluate whether science team enhancements will be valuable or affordable using a scrubbed version of the budget.

The panel thought that the team was somewhat myopic about science applications and focused on operational relevance. This argues that the mission could benefit from being opened up competitively to broader communities.

Project Name: SAGE

The Stratospheric Aerosol and Gas Experiments (SAGE) operates on the Earth Radiation Budget Satellite launched into a 57-degree orbit in 1984 (SAGE II) and was also launched on a Russian Meteor 3M spacecraft in December 2001 (SAGE III). SAGE II employs a solar occultation technique to measure line-of-sight transmission profiles at seven wavelengths from the ultraviolet to the near infrared. SAGE III employs a similar method at 87 wavelengths to produce profiles of ozone, nitrogen dioxide, water vapor, temperature, and aerosol extinction at nine wavelengths. The SAGE proposal incorporated the science operations of both the SAGE II and SAGE III instruments as well as operating the ERBS spacecraft which hosts both the SAGE II and ERBE instruments.

Spacecraft /Instrument health and status: SAGE II is on an aging satellite (ERBS) with a degrading power system and may not last much longer. The instrument has some degradation in the reflectivity of the scan mirror and in the instrument photodiodes. The free motion of the azimuthal rotor is also inhibited. The end of the unique 25-year SAGE I – II record of stratospheric profiles of ozone and aerosols is imminent.

SAGE III is on a Russian satellite in an orbit that limits occultation measurements (its primary mission) to high latitudes. The Russian Space Agency has extended mission for two additional years (2005 and 2006) with the spacecraft capable of being extended to 2007. The instrument is performing as designed, with no obvious negative rends in thermal, electrical and mechanical subsystems. The Russian collaboration is working well. The original instrument design (for 2 solar occultations per orbit plus some stellar occultations) has led to a data system that is limited to about 55 profiles per day.

Science Strengths: SAGE data have traditionally made strong contributions to ozone assessments, with its multi-decade record of stratospheric ozone and aerosols. This ozone record is not only a key part of NASA's heritage in reporting on the health of the ozone layer, but also has provided a wide range of science on chemistry-climate interactions that can only be evaluated with such a record. The science from the SAGE record of aerosols was critical in following large volcanic eruptions (Mt. Pinatubo) and the related ozone loss.

The proposal would try to continue this important record with SAGE II (as long as it lasts) but would put more effort into exploring limb scattering for ozone profiles with SAGE III. The scientific team involved has an impressive record.

Relevancy Strengths to Earth Science Strategic Plan: As noted, reporting to Congress on the state of ozone-layer science is a specific mandate of NASA, and NASA has led in the detection of ozone trends along with an understanding of the role of humans play in those trends. The previous SAGE record has been absolutely critical in determining the vertical profile of ozone depletion (as has TOMS in the geographic and seasonal patterns of ozone column depletion). The importance of the SAGE record in the international negotiations of the Montreal Protocol cannot be understated.

Data operations (accessibility, quality control, archiving): There are some issue about monthly or weekly data segments. The key limitation of SAGE III is the limited number of profiles that can be acquired per day.

E/PO comments: The Review Team does not have additional comments beyond the assessment and recommendations of the prior E/PO review.

Proposal Weaknesses: This proposal reflects tactical issues rather than scientific ones. For science, SAGE II has a much better orbit, but the spacecraft and instrument are aging and vulnerable. In contrast, SAGE III is a far superior instrument (in design and in current capability) but provides more limited science opportunities because of its orbit. The proposal puts top emphasis on developing SAGE III as a limb scanner using scattered light rather than solar occultation, thus opening up SAGE III for global coverage. The panel does not agree with the proposed priorities.

SAGE III occultation (its design goal) can only yield limited results (high latitudes, e.g., polar ozone studies) due to the orbit limitations. It has proven very useful in studying polar ozone loss, but there are several satellites making similar high-latitude measurements. The proposal to move into limb scattering measurements extends SAGE III to all latitudes and potentially thousands of more profiles, but the data system cannot support a greatly enhanced observing cycle. Hence, the move to limb scanning can only report 50 profiles per day as opposed to tens of thousands for typical limb scanning satellites.
If the SAGE III extension and shift to limb scanning produced a 'new' satellite (with the potential for many more years as appears likely), this panel would have reviewed this effort differently.

Since SAGE III is just developing and validating the limb-scan algorithms, the panel noted some risk (skepticism) in efforts to do new algorithm development. To be useful such development would have to be applied to OMPS (NPP). In upcoming efforts to use the OMPS profiling, the panel recognized a significant role for the SAGE team, but felt that the proposal as written was somewhat off target, and that many other groups are also involved in such retrievals with existing satellites.

Proposal does not seem to be aware of other efforts in the rest of the world (e.g., ESA, TES) for issues like air quality; the use of SAGE III for aerosol and gas studies is very stretched.

Baseline and Optimal Missions: No funds are being sought for an optimal mission. If resources are not available to extend both SAGE II and SAGE III, then the PIs suggest that SAGE III has the lowest risk and will provide greater scientific value.

Overall assessment: The continuation of SAGE measurements ranks low in priority because SAGE II is not anticipated to last much longer and SAGE III, although much healthier, is in the wrong orbit to achieve the most important sciences objectives, such as

continuation of the SAGE record. If SAGE II ends, we are concerned that there will be no team dedicated toward continuing a climate-quality ozone profile record to help transition into the NPOESS era.

The Review Team recognizes the critical need to maintain the SAGE II record of ozone and aerosol profiles (monthly zonal means) for another decade. Considerable scientific returns in the area of chemistry-climate coupling would be expected for such a record. This is high priority. It is clear that this direct record cannot be maintained for very long (nor reliably) by SAGE II. Therefore, this record needs to transition to other modern instruments that - although operating in different modes and resolutions - would still be able to carry the scientifically interesting record of stratospheric ozone-aerosols-climate forward. The best we can hope for is the overlap of SAGE II with Aura (MLS & HRDLS). This effort was not proposed although it is needed.

The transition of SAGE III from a polar occultation satellite to a global limb-scanner cannot be done in isolation since the SAGE III data stream is too limited for serious global measurements. This is particularly true in the troposphere given the variability and lack of any meaningful science from 50 profiles per day (as opposed to the stratosphere where zonal averages are more acceptable). The panel could not support this direction without a more coherent NASA-wide strategy in acquiring ozone profiles.

This brings up another important issue. The panel was very impressed with the dedication of the TOMS team toward obtaining a climate-quality total ozone record. We also note that with the anticipated end of SAGE II there does not exist to our knowledge an analogous team dedicated toward a climate-quality ozone profile record. This will be particularly important as we move into the NPOESS era.

Project Name: Terra

Terra is the EOS flagship platform that provides multiple data products for integrated studies of land, ocean, atmosphere, hydrosphere and cryosphere. The spacecraft carries five instruments – MODIS, CERES, MISR, ASTER and MOPPIT. MODIS provides a suite of land, ocean and atmosphere products. CERES provides cloud property estimates and the Earth's total radiation budget. MISR is a multi-view angle instrument providing measurements of the bidirectional reflectance properties of surfaces (e.g., clouds, aerosol particles and land). ASTER provides a multi-spectral (visible to thermal infrared) sampling of land surface temperature, emissivity, reflectance, and elevation at high spatial resolution (15 to 90 m^2 per pixel). MOPPIT provides measurements of column carbon monoxide concentrations using gas correlation spectroscopy. These sensors provide more than 40 data products applicable to a wide range of science objectives in the NASA research areas of: (a) climate variability and change, (b) atmospheric composition, (c) carbon and ecosystems, (d) energy and water cycle, (e) weather, and (f) Earth surface and interior.

Spacecraft /Instrument health and status: The Terra spacecraft and its five instruments are reportedly in good health. Although MOPPIT suffered a partial failure in 2001, the instrument continues to provide data and is said to be "very stable", providing one of its primary data product of column integrated carbon monoxide concentration. There is sufficient propellant onboard Terra to extend the mission for another nine years.

Science Strengths: The major strength of Terra is the suite of instruments that provide concurrent multiple observations pertinent to terrestrial, oceanic, atmospheric, hydrospheric and cryospheric science. A related strength is the demonstrated calibration and validation of a variety of Terra products.

The proposal focuses on three broad goals: (1) continuation of the data processing stream, (2) improvement of current products based on multi-sensor data fusion, and (3) analysis and development of new products (e.g., forest structure and biomass) from multi-sensor (Terra and non-Terra instruments) data fusion. All three goals are of critical importance to achieving NASA science objectives.

The panel noted the additional importance of ASTER data as a partial data gap filler for the compromised Landsat 7 ETM+ sensor.

The panel also recognized that MODIS and CERES measurements from both the Terra and Aqua satellites are complementary and should not be seen as simply redundant. Differences in overpass time result in significantly different measurement environments (clouds, smoke, cloud-free areas) and thus different science questions and applications that can be addressed.

Relevancy Strengths to Earth Science Strategic Plan: Terra observations are core to the NASA Earth Science Strategic Plan. As indicated above, Terra measurements

provide critical data for integrated analysis of Earth system processes as well as for weather and hazard analyses and prediction.

Data operations (accessibility, quality control, archiving):
1) The data are accessible via EOSDIS, PI websites, and other pathways.
2) The EOSDIS is widely recognized as being difficult to navigate and has limited the number of users. Efforts have been made to improve the system, such as the discipline processing team for Oceans.

E/PO comments: The Review Team does not have additional comments beyond the assessment and recommendations of the prior E/PO review.

Proposal Weaknesses: The extended mission looks promising, but approaches to facilitate multi-sensor data fusion were not sufficiently defined. There were several good examples provided for possible data fusion efforts (e.g., CERES-MODIS-MISR for a new polar cloud and radiation data product), but a strategic plan to maximize multi-sensor data fusion for improved or new data products is essential at this stage in the Terra mission. We therefore strongly suggest the need for developing a strategic plan and framework to facilitate data fusion studies.

Future NRAs run out of Terra Project Science Office and NASA Headquarters are strongly supported, and are included in the Terra baseline and optimal budgets. However, a budget breakdown was not provided for this science and research portion of the proposal.

Because of problems in calibrating MODIS ocean bands to the uncertainty levels necessary to provide accurate products, processing of these data has been placed on an indefinite hold. This has lead to a gap in generating a consistent analysis of global terrestrial and oceanic biomass/productivity. There have been extensive advancements in calibration and validation of MODIS oceans channels by focusing on the more stable MODIS instrument on the Aqua platform. In addition, these insights and improvements have been enhanced by the involvement of the Ocean Discipline processing team at GSFC. The committee supports a plan in which the extension of the Terra mission would include a reanalysis of the calibration and product generation for the ocean component.

Baseline vs. Optimal Mission Budgets: The baseline mission offers to continue current operations with some additional emphasis on E/PO. The baseline mission is essential for continued operations and science data production. The optimal mission offers a suite of new scientific endeavors, several of which focus on fusion of Terra data measurements. The optimal mission is strongly supported in order to exploit the full potential of combined Terra measurements and observations from other satellite platforms.

In addition, the Terra mission team indicated that including additional efforts to generate calibrated radiance for the ocean could be supported by the requested optimal budget. We find that this would be an important activity to pursue even if the full optimal budget is not authorized.

The mission extension budget (baseline or optimal) currently includes NRA-related science (approx. $22M/year). We believe that the focus of this competed science program should be used to facilitate new (guest) investigations with particular focus on the fusion of different Terra products and measurements from other missions.

Overall assessment: The Review Team is in strong support of continuing Terra in order to achieve: (1) continuation of the data processing stream, (2) improvement of current products based on multi-sensor data fusion, and (3) analysis and development of new products (e.g., forest structure and biomass) from multi-sensor (Terra and non-Terra instruments) data fusion. Support at an optimal funding level should depend on the development of a strategic plan for data fusion studies that can be implemented and executed by the proposed Terra Project Science Office (and mediated by NASA Headquarters). Facilitation of new guest investigation to focus on fusion of different Terra products and measurements is needed.

Project Name: TOMS

The core of the EP/TOMS (Earth Probe Total Ozone Mapping Spectrometer) proposal is to maintain and extend the record of total ozone in support of NASA obligations and in direct support of the Strategic Plan. The support requested is partially for the extension of the EP/TOMS mission and partially for processing OMI data in an effort to extend the existing TOMS record with a consistent overlapping dataset from Aura/OMI and would extend into the NPP/NPOESS era. The scientific payoff here falls under the topic of long-term tracking of the composition of the atmosphere and is central NASA's Earth science objectives of understanding ozone and climate change.

Spacecraft /Instrument health and status: The strength of continuing the EP/TOMS is for mapping, not long-term calibration. That instrument is rapidly approaching the end of its utility and has problems. The new Dutch instrument OMI on Aura was meant to continue the TOMS record of daily global column ozone measurements. Unfortunately, OMI has problems related to slow degradation of its CCD sensors, and it is appears that the instrument will meet its 5-year mission requirement but will not provide the hoped-for decadal record. This proposal is basically for the continuity of the ozone column record from 1979 into the NPP/NPOESS era. It incorporates efforts involving the existing TOMS E/P and OMI sensors and prepares for the OMPS sensor (NPP) to be brought online to extend the TOMS record (which extends back to 1970 BUV).

Science Strengths: This proposal would maintain the ongoing long-term effort to understand the dynamics of stratospheric ozone. This effort has been instrumental in studies of the "ozone hole" as well as initially detecting the long-term depletion of ozone on a global-scale. Indeed, the TOMS-produced maps of the ozone hole have been one of the most visible efforts in monitoring global change. The detection of ozone depletion on a global scale (combining TOMS and ground-based data) was a watershed result of the WMO/UNEP 1988-89 Ozone Trends Panel that led to and justified the complete phase-out of CFCs in the London Amendments.

The TOMS record of total ozone is a well-calibrated and reliable record approaching three decades in duration. The proposal appropriately addresses the development of bridges to new sensors (OMI on Aura and OMPS on NPP). For the immediate future the EP/TOMS instrument serves as an inexpensive backup for the OMI sensor that has experienced some difficulties associated with the use of an innovative CCD sensor array**.**

The proposal notes the range of ozone-measuring satellites available, including the contributions from ESA, and appropriately integrates those efforts into their plans.

The strength of the proposed science derives from long-term monitoring and is precisely the approach needed to be able to document the existence of change in the atmosphere. While this approach may not be considered engaging as it does not have lots of "new science," it is important and arguably essential to the study of global change.

The TOMS team (along with other scientists) has developed algorithms for detecting other atmospheric constituents that are detectable by scattered UV (overlapping with ozone). The most important of these are tropospheric ozone (about 10% of the column and not easily retrieved) and absorbing aerosol from fossil fuel combustion and natural biomass fires (this is a unique product from the UV TOMS algorithms that is a key, auxiliary, independent aerosol measurement).

The TOMS ozone record is important to the processing of a variety of other satellite datasets (e.g., ocean color, PAR) and without it many other programs would be in trouble.

Relevancy Strengths to Earth Science Strategic Plan: This proposal is highly relevant. It contributes significantly to NASA's mandated effort under the 1977 Clean Air Act Amendment to report to EPA and Congress on the state of knowledge of the stratosphere. Additionally, monitoring of stratospheric ozone contributes to "taking the pulse of the home planet". Indeed, the NASA ESS Strategy specifically identifies the importance of "capturing and documenting dynamics of Earth's Ozone layer and understanding the effects of its depletion on exposure to UV radiation at the Earth's surface" (p. 12).

Data operations (accessibility, quality control, archiving): All appears to be progressing appropriately in this domain. The team has done this effectively for a long time.

E/PO comments: The Review Team does not have additional comments beyond the assessment and recommendations of the prior E/PO review.

Proposal Weaknesses: There are no substantial weaknesses in this proposal. The only weakness discussed by the panel was the lack of "exciting new science" (with the exception of the effort to recover aerosol distributions from past datasets and extend the aerosol record back in time). There is, however, emerging new science about decadal variability (solar cycle, PDO, etc) for which the extended TOMS record (plus the SAGE profiles) provide the only global patterns of atmospheric trace constituents.

Baseline and optimal missions: The primary cost associated with the proposal is support of scientists working on the production of long-term climate data records, as opposed to the actual operation of the satellite and the collection of data. In fact, most of the cost is to support analysis of data from OMI.

The baseline mission would provide the essential continuity of the ozone record. It includes continuing the EP/TOMS mission (hence this review), continuation of the long-term ozone datasets with merging/reconciling the other satellite ozone records. Also included is the calibration effort along with algorithm (e.g., from OMI and others) and data quality evaluation.

We support the inclusion of the dimension of the proposed optimum budget related to the exploration of the recovery of aerosol information. The panel feels that the possibility of producing an historical record of aerosols is well worth pursuing**.**

Overall assessment: The TOMS proposal contributes significantly to NASA's mandates to monitor the stratosphere and ozone. The baseline mission would provide continuity of the ozone record. Efforts to pursue an historical record of aerosols using TOMS are worth pursuing. The overall assessment is to fund the "in-guide" proposal as well as the component of the "optimum" proposal related to extending the aerosol record. The panel felt that the component of the "optimum" proposal related to funding additional science team members should be competed independently.

This well-written proposal addresses important science issues. It builds on an impressive history of accomplishment, the first spaceborne, global datasets of sufficient quality to quantify trends in atmospheric composition. The proposal contributes significantly to NASA's mandates to monitor the stratosphere and ozone. It includes a creative approach for minimizing the costs of operating the mission through collaborative efforts with a local college. The science benefit is large relative to the cost. The nature of the science is important, but not sexy. It requires patience, but in the long run it has tremendous value in terms of tracking changes in the environment.

Experience demonstrates the value of baseline support for scientists working on the myriad issues involved in building top quality datasets for long-term monitoring of the environment. Many measurements are moving to new spacecraft or new types of sensors, and therefore the need for this baseline support may be increasing. One of the strengths of this proposal is the recognition of the need to support the development of operational algorithms and calibration facilities for other sensors that are directly comparable with the existing record. We find that this form of continuity is valuable and important for support. More than most proposals, the TOMS proposal both acknowledges and embraces the integration of data from multiple sources and represents progress toward the goal of moving away from "missions" toward "measurements."

Project Name: TRMM

The Tropical Rainfall Measuring Mission (TRMM) has been a success for NASA. The number of publications, including operational papers, has grown exponentially since launch. The instruments are in good working order; the critical issue is the fuel remaining and whether a waiver will be issued to allow an uncontrolled re-entry.

Spacecraft /Instrument health and status: The Tropical Rainfall Measuring Mission was launched in November 1997, with data available from December 1997. The PR, TMI, VIRS, and LIS instruments have remained in excellent working order. However, within the next few months, TRMM will reach a decision point, when the minimum amount of fuel necessary for a controlled re-entry is remaining. The baseline case is to bring TRMM down in a controlled re-entry; the requested optimal funding is to keep TRMM on station, which could keep the satellite up until roughly 2012, but necessitating an uncontrolled re-entry.

Science Strengths: If the TRMM instruments remain in orbit, the following science questions could be addressed: (1) an improved climatology of tropical precipitation characteristics could be developed, allowing for precipitation statistics for regions smaller than basin-scale. It is hoped that the improved climatology could allow for the exploration of precipitation/cloud/latent heat processes and better understanding of critical scales in climate models. (2) Calibration with future missions such as GPM and CloudSat are a plus. Having both TRMM and CloudSat in space at the same time would allow the exploration of the precipitation-aerosol link, and could also enable improved algorithms; the unique synergy with the CloudSat 95 GHz radar allows the start of understanding the frequency dependence of rain rate algorithms, although this would necessitate some way of achieving 'ground-truth.' (3) It is anticipated that more tropical cyclones will be measured by TRMM, and this will enhance our understanding (especially if the precipitation radar is able to sample a larger number of tropical cyclones than has been sampled to this point). (4) An extended mission makes it possible to investigate the impact of different decadal/interannual phases on over-ocean precipitation or heat balance effects. This is particularly important if ENSO, PDO, and/or NAO phases influence the probability of sudden intensification.

Relevancy Strengths to Earth Science Strategic Plan: TRMM offers key data for a number of NASA Strategic Science Questions, with the main benefits addressing the NASA issues of global precipitation and water cycle variability, and the relation to global climate variation, weather forecast improvement, and water cycle dynamics predictions improvement.

Data operations (accessibility, quality control, archiving): The data are accessible via GSFC DAAC, among other locations. The data are extensively used by the greater community, as evidenced by the volume distribution of the products at DAAC. The number of papers in the last four years alone is over 400, with roughly 75 of those relating to operational aspects of TRMM data (significant growth in both science and operational papers has occurred within the last two years).

E/PO comments: The Review Team does not have additional comments beyond the assessment and recommendations of the prior E/PO review.

Proposal Weaknesses: Some of the science questions to be addressed needed a stronger quantitative basis for assertions, such as improved understanding of extreme events, aerosol/rain connections. It is likely that a few more strong hurricanes will be observed during an extended lifetime, but it is less likely that statistically the additional numbers of, for instance convective thunderstorms, will significantly enhance our understanding or our statistics. The use of TRMM data for making climate data records is also suspect, unless there is some effort to address physical retrievals so that it would be possible to combine data sets with GPM. The only issue covered in the validation discussion is the ground validation program, and the emphasis there is on more data over various times, rather than on other scientific methods that could be used to improve the algorithms. Although the uniqueness of TMI for SST measurements was pointed out, the scientific benefits of the use of this data and possible methods for inclusion of this data in longer-term data sets were not highlighted, and could have strengthened the proposal. The budget analysis was also difficult to understand relative to the proposal.

Baseline and optimum missions: It is difficult to determine from the proposal what the baseline and optimum missions are. It appears that the baseline mission will occur if a waiver to continue TRMM is not granted. The optimum mission case appears to be continued TRMM operations. However, the budgets do not entirely support this viewpoint.

Overall assessment: The operational benefits are high for continuing the precipitation measurements and spatial/temporal resolution that is available only from the TRMM suite of instruments. In fact, the operational benefits of TRMM seem to be more compelling than the possible science benefits of continuing the mission, which did not receive a strong endorsement from the committee. It appears that much of the budget is for GPM activities, unless there is $15M budgeted for TRMM Science Team members, which is too high based on the science proposed. If a waiver for TRMM is not granted, the Review Team believes that TRMM should scale down activities and emphasis should be given to the GPM transition.

Project Name: UARS

The Upper Atmospheric Research Satellite (UARS) mission has been one of NASA's triumphs. It was a highly integrated suite of instruments for studying stratospheric ozone and stratosphere/climate interactions. UARS has been responsible for much of the knowledge we now have about the stratosphere, its chemical constituents, and about stratospheric ozone. In addition, UARS has produced excellent measurements of total solar irradiance, solar spectral irradiance, and energetic particle fluxes into the upper atmosphere.

UARS was launched in September 1991. Over 1,000 (and perhaps as many as 2,000) publications using its data have appeared. If it continues operation, it can still yield valuable HALOE measurements during the anticipated O_3 recovery (from CFCs). It would also give good data on water vapor and O_3 in the upper troposphere/lower stratosphere region. These data would help in separating solar, volcanic, and anthropogenic effects on ozone. Further, the particle instruments would continue to improve our knowledge of energetic particle fluxes and their impacts on the upper atmosphere. On the other hand, we now have the Aura instruments and other satellite or ground-based data that overlap with the UARS data.

Spacecraft /Instrument health and status: UARS is now in its 14^{th} year of operation, and time has taken its toll. The spacecraft is operating in a reduced power state, its battery capabilities are a fraction of what it started with, and it has much reduced tape recorder capability. ISAMS, CLAES, ACRIM, and WINDII are no longer operating. On the other hand, HALOE is still producing excellent data. SOLSTICE and SUSIM are producing excellent data on solar spectral irradiance, and HRDI and PEM although still operational are in reduced capability modes. UARS must use TDRSS, since it has only partial use of one tape recorder.

Science Strengths: Arguments for continuing operation of UARS hinge on (1) importance of HALOE water vapor; (2) HCl measurements to better understand ozone during predicted ozone turn-around; (3) overlap with AIM SOPHIE instrument measurements of NO; and (4) HALOE measurements of O_3. At least one-year overlap with relevant Aura measurements would help in constructing a continuous record for many stratospheric constituents. Since HIRDLS became operational in January 2005, there is a strong argument to operate UARS with at least one-year overlap, or until at least January 2006. The SOPHIE instrument is scheduled to be launched in September 2007. A one-year overlap with SOPHIE would imply HALOE operations until September 2008.

Relevancy Strengths to Earth Science Strategic Plan: UARS' 13+ years of measurements relate strongly to NASA's goals of understanding the changing atmospheric component of the climate system. NASA has been designated as the responsible federal agency to understand the stratospheric ozone layer. This and Landsat are the only activities that the US Congress has so specifically mandated to NASA.

Data operations (accessibility, quality control, archiving): The UARS data algorithms are mature. Its data are readily accessible through the GSFC DAAC. The quality of its data is good, and the data are being archived.

E/PO comments: UARS operation by the Space Operations Institute is financially very efficient, and this arrangement provides good student training. Other aspects of the UARS E/PO are not compelling.

Proposal Weaknesses: UARS is an aging satellite, and Aura has many of the UARS capabilities.

Baseline and optimum missions: The baseline scenario is to operate HALOE only. The optimal mission is to operate all remaining functional instruments.

Overall assessment: Given limited NASA resources, we feel that it is important to continue the UARS mission only into early 2006 to assure UARS/Aura continuity of crucial measurements relating to stratospheric ozone. We do not find the arguments compelling for a UARS extension for overlap with the SOPHIE instrument on ACE.

UARS' capability is down a great deal from what it was originally. It has some excellent instruments still functioning that are giving valuable information. The present UARS extension was justified by traceability, mainly for Aura. This could be accomplished with about 1 years of overlap, i.e., into early 2006. This should insure that the HALOE H_2O and HCl can be related to those by MLS on Aura with confidence.